AD 654173

R 531

Technical Report

PROTECTION OF MOORING BUOYS

PART IX. RESULTS OF EIGHTH RATING INSPECTION

June 1967

NAVAL FACILITIES ENGINEERING COMMAND

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

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CONTENTS

PROTECTION OF MOORING BUOYS — PART IX. RESULTS OF EIGHTH RATING INSPECTION

Technical Report R-531

Y-F020-03-04-003

by

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ABSTRACT

This is the ninth of a series of reports on the protection of mooring buoys. Thirteen buoys were given their eighth rating (after a maximum of 4-1/2 years exposure) for extent of coating deterioration, corrosion of steel, and fouling. Two other buoys had previously been removed from testing in San Diego Bay because of advanced deterioration. The coating systems on three of the buoys were in good condition, while those on 10 others showed varying degrees of moderate deterioration. Two sets of 13 steel panels each, coated with the different systems used on the buoys, were given their seventh rating inspection after 3-1/2 years of exposure. One set was exposed in San Diego Bay and the other in Port Hueneme Harbor. The condition of the coatings on both sets of panels was generally better than that of the buoy coatings, but there was a general correlation between the conditions of the two test groups. On buoys coated with antifouling paints, no detectable antifouling property remained after 20 months, but on both sets of test panels, two antifouling coatings containing copper oxide were still appreciably reducing fouling after 3-1/2 years.

Patches of underwater-curing epoxy applied to buoys where localized damage to the coating had been caused by abrasion were in good condition. Some patches had been in place for 3-1/2 years.

Three of the buoys were cathodically protected with zinc anodes. The underwater portions of these buoys were receiving protection from corrosion 28 months after anode installation.

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INTRODUCTION

The Naval Facilities Engineering Command assigned the Naval Civil Engineering Laboratory the task of finding or developing better methods for protecting Fleet mooring buoys from corrosion. The assignment included investigation of both protective coatings and cathodic protection.

A field-test program was initiated in San Diego with 15 peg-top riser-chain mooring buoys (Mark I or Mark II). Thirteen different coating systems were used, and a cathodic-protection system was installed on one buoy of each of three pairs used in this part of the test program. The same thirteen coating systems were also applied to two sets of test panels, one exposed in San Diego Bay and the other in Port Hueneme Harbor. The results of the program are being published in a series. Technical Report R-246,[1] the first in the series, described the application of protective coatings and the installation of a cathodic-protection system. Subsequent reports[2-8] described the condition of the buoys from the first through the seventh rating inspections and the condition of the panels through their sixth rating inspection. This report describes the condition of the buoys at the time of their eighth rating inspection (up to 4-1/2 years exposure) and the condition of the panels after 3-1/2 years of exposure.

SERVICE CONDITIONS

For the test, 15 mooring buoys were placed in an area of North San Diego Bay that received heavy service from the Fleet. Some of the buoys were badly damaged by overriding vessels and by the abrasion of mooring lines and securing assemblies. Because it was necessary to place the test buoys in service a few at a time, and because there were long delays in obtaining acceptable specification coatings, preparation and placement of all the buoys required a long time.

One set of 13 panels was suspended from a pier in San Diego Bay and the other from a pier in Port Hueneme Harbor. A portion of each panel was continuously submerged, another portion was intermittently submerged by rising tide, and a third portion was continuously exposed to the atmosphere. The panels were not exposed to their harbor environments at the same time as the buoys; they were kept in storage until all of them had been coated. All the panels were then placed in test position at the same time, rather than over a 6-month period as were the buoys. At the time of their seventh rating (described herein) they had been exposed for 3-1/2 years.

INSPECTION PROCEDURE

Each of the test mooring buoys was inspected after it had been lifted onto the deck of a floating crane. The amount of fouling was determined, the types of organisms were recorded, and fouling damage to the coating was noted. After the fouling was examined, the cone and splash zone of each buoy was washed with a high-pressure stream of seawater to remove the fouling and expose coating damage. Two independent ratings of the condition of each buoy and its protective coating system were made in the atmospheric, splash, and submerged zones.

Electrical potential measurements were made on buoys with and without cathodic protection to determine the amount of additional potential produced on cathodically protected buoys. The coating deterioration and corrosion damage of the three cathodically protected buoys were compared to those of the control buoys.

Two independent ratings were also made of the condition of the coating systems on the steel test panels exposed in San Diego Bay and Port Hueneme Harbor. Fouling organisms were carefully removed from one side of each test panel with a wooden scraper and a stiff brush before rating the coating condition in the fouled area.

RATING CRITERIA

So far as possible, the methods of rating the coatings on buoys and test panels were those published by the American Society for Testing and Materials.[9] These published methods define the conditions rated and give photographic reference standards. Thus, chalking, blistering, checking, cracking, flaking, erosion, and rusting were rated from 0 to 10 by ASTM methods D-659-44, D-714-56, D-660-44, D-661-44, D-772-47, D-662-44, and D-610-43, respectively. A rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. Blistering frequency was rated as none (N), few (F), medium (M), medium dense (MD), or dense (D). Surface areas covered by fouling (plant, animal, or a combination) were rated on a linear scale from 0 (100% covered) to 10 (0% covered). Color of the topcoat on the buoys was also rated from 0 to 10; 10 indicates pure white with no yellowing or other discoloration (except rust streaks from uncoated bolts), and 0 indicates a color unacceptable to the U. S. Coast Guard.

Frequency of use of buoys by the Fleet was rated as light (0 to 2 days per week), medium (2 to 4 days per week), or heavy (4 to 7 days per week). Some of the buoys provide bow and stem mooring only, and the rest provide either bow and stem or free-swinging moorings.

The overall condition of each buoy and its coating system was rated as excellent (in essentially the same condition as when first placed in service); good (very minor deterioration); fair (a significant amount of coating deterioration or rusting, but still in serviceable condition); and poor (coating deterioration and rusting serious enough to lead to an early removal from service).

The coating system on each test panel was given an overall rating from 0 (minimum protection) to 10 (maximum protection), depending upon both the condition of the entire coating system and the protection afforded to the steel. It was much easier to rate the overall coating conditions on the panels than on the buoys, because the panels were not abraded as were the buoys during mooring service.

CONDITION OF BUOY COATINGS

General

Table 1 describes each coating system. The overall ratings and lengths of service of buoy coatings are summarized in Table 2. The sources of the proprietary coatings tested are listed in References 2 through 4. These reports are available only to U. S. Government agencies and their contractors with a need to know. Ratings of specific conditions of coated test buoys are given in Appendix A.

The fouling on all test buoys was generally similar both in type and amount, with slightly differing amounts occurring in different test areas. Green algae and barnacles were most conspicuous in the splash zone. Tunicates and barnacles were most conspicuous in the submerged zone, and mussels, bryozoa, hydroids, and tube worms were usually present to a lesser extent.

The Mark I test buoys usually had marine borer damage on their lower, untreated wooden fenders. The lower, creosoted fenders of the larger Mark II buoys were almost always completely out of the water and suffered no marine borer attack.

Coating System 1: Urethane

The condition of the System 1 buoy (Figure 1) had not changed much since the previous rating inspection. The slight pinpoint rusting on the buoy, especially in the splash zone, may have been initiated by the small blisters previously noted there.

The many patches of underwater-curing epoxy,[10] most of which had been applied 3-1/2 years earlier to underwater areas damaged by the impact of moored vessels, were still adhering tightly to the underlying steel and providing good protection from corrosion despite the previously reported[3-8] lifting of the edges of some of these patches where they extended over weathered coating.

Moderate galvanic corrosion of the bolts securing the lower lateral fender in place is shown in Figure 2. Teredo damage to this wooden fender is also shown in this figure.

Table 1. System Description and Coating Thickness

System		Primer			Additional Coats			Total Thickness (mils)
Number	Description	Type	Coats (No.)	Thickness (mils)	Type	Coats (No.)	Thickness (mils)	
1	Urethane	Urethane	1	2	Urethane	3	8	10
2	Epoxy	Epoxy	1	4-5	Epoxy	1	4	8-9
					Epoxy	1	3	11-12
					Antifouling	1	4	15-16
3	Epoxy-Polyester	Epoxy	1	4-5	Polyester	2	5-6	9-11
					Antifouling	1	4	13-15
4	Epoxy-Coal Tar Epoxy	Epoxy	1	4	Coal Tar Epoxy	1	4-5	8-9
					Epoxy	1	4	12-13
					Epoxy	1	4	16-17
5	Coal Tar Epoxy-Phenolic	Coal Tar Epoxy	1	5	Phenolic	1	4-6	9-11
					Phenolic	1	6-7	15-18
6 & 6C	Phenolic Mastic	Mica-filled Phenolic	1	10-11	Phenolic Mastic	1	8-9	18-20
7C	Phenolic	Wash Primer	1	1/2	Phenolic	1	2-3	7-8
		Phenolic	2	4 1/2	Antifouling	1	3	8
8	Phenolic-Alkyd	Wash Primer	1	1/2	Alkyd	1	2-3	7-8
		Phenolic	2	4 1/2	Antifouling	1	3	8
9	Vinyl	Wash Primer	1	1/2	Vinyl-alkyd	3	4	11-12
		Vinyl	4	6 1/2-7 1/2	Antifouling	2	4	11-12
10	High-Body Vinyl	Vinyl	1	2	Vinyl	2	5-6	7-8
					Vinyl	1	2	9-10
11	Vinyl Mastic	Vinyl Phenolic	1	1-2	Vinyl Mastic	2	12-13	13-15
12	Inorganic Zinc Silicate-Vinyl Mastic	Inorganic Zinc Silicate-Vinyl	1	4	Vinyl Mastic	1	5-6	10-12
		Phenolic	1	1-2				
13 & 13C	Saran (Formula 113 54)	—	—	—	Saran	8	8	8

Table 2. Overall Rating and Length of Service for Coated Buoys

Coating System		Length of Service (months)	Overall Rating
Number	Description		
1	Urethane	51	good-fair
2	Epoxy	49	good
3	Epoxy—Polyester	49	fair
4	Epoxy—Coal Tar Epoxy	51	good-fair
5	Coal Tar Epoxy—Phenolic	49	fair
6	Phenolic Mastic	49	good-fair
6C	Phenolic Mastic	49	good
7C	Phenolic	44	good-fair
8	Phenolic—Alkyd	44	good-fair
9	Vinyl	45	good-fair
10	High-Body Vinyl	—	removed from test
11	Vinyl Mastic	—	removed from test
12	Inorganic Zinc Silicate—Vinyl Mastic	51	fair-poor
13	Saran	49	good-fair
13C	Saran	50	good

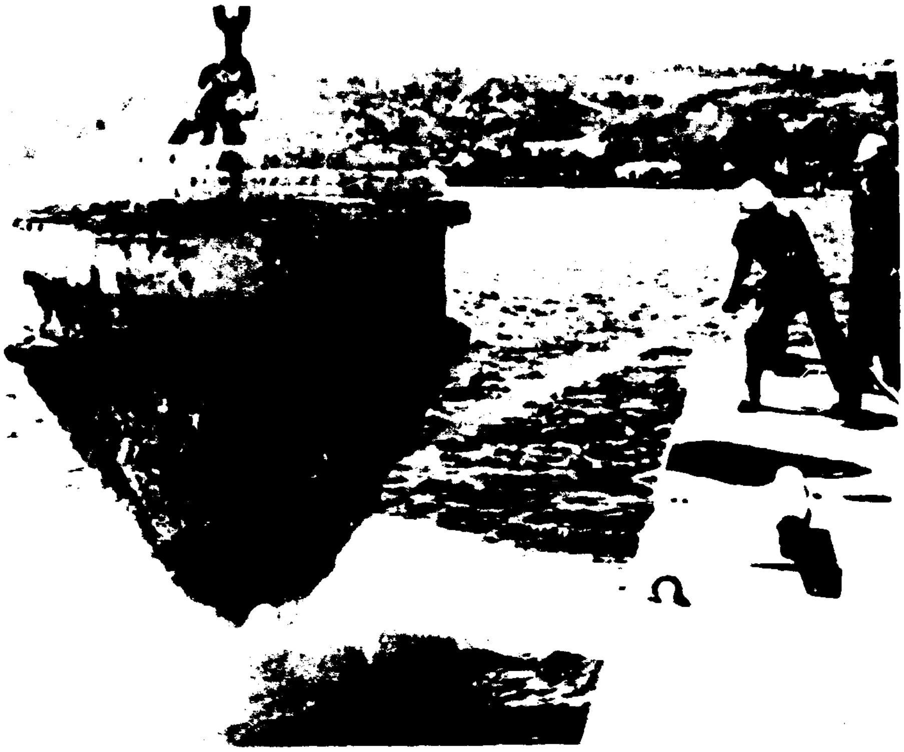

Figure 1. Hosing off System 1 buoy.

Figure 2. Galvanic corrosion of System 1 buoy bolts.

Coating System 2: Epoxy

The condition of the System 2 buoy (Figure 3) was essentially unchanged since the last inspection. The two areas where impact dumage to the coating had been patched with underwater-curing epoxy 1 year earlier[7,8] were receiving full protection from these patches (Figure 4). Aside from the previously noted[5] areas of slight corrosion caused by abrasion, System 2 was providing good protection. A few of the rivet heads in the submerged zone of this Mark I buoy had some galvanic corrosion where paint had been removed by abrasion.

Coating System 3: Epoxy–Polyester

The condition of the System 3 buoy (Figure 5) was essentially unchanged from that noted at the last inspection. The epoxy primer exposed in the sumberged zone where much of the polyester topcoating had delaminated was continuing to protect the underlying steel. The rusting in all three zones was related to abrasion damage. As noted on the previous Mark I buoy (System 2), there were in the submerged zone a few rivet heads undergoing galvanic corrosion initiated by abrasion of the coating.

Coating System 4: Epoxy–Coal Tar Epoxy

The condition of the System 4 buoy was essentially unchanged since the last inspection. The previously noted delamination of the topcoat and seal coat in the submerged zone had not advanced significantly since the last inspection, and the underlying epoxy primer and coal tar epoxy were providing good protection to the steel. Elsewhere, the entire coating system was performing well with the slight rusting noted related to abrasion damage.

Coating System 5: Coat Tar Epoxy–Phenolic

The condition of the System 5 buoy (Figure 6) was essentially unchanged since the last inspection. Most of the coating damage was related to abrasion. Abrasion had initiated galvanic corrosion of some rivet heads in the submerged zone, as had occurred on most of the other Mark I buoys.

Coating System 6 and 6C: Phenolic Mastic

Systems 6 and 6C were identical, but the 6C coating was applied to a cathodically protected buoy. The condition of both buoys (Figure 7) was essentially unchanged since the last inspection. The deterioration on each was largely a result of abrasion damage, and the better condition of the System 6C buoy is a result of the cathodic protection and the heavier fendering.

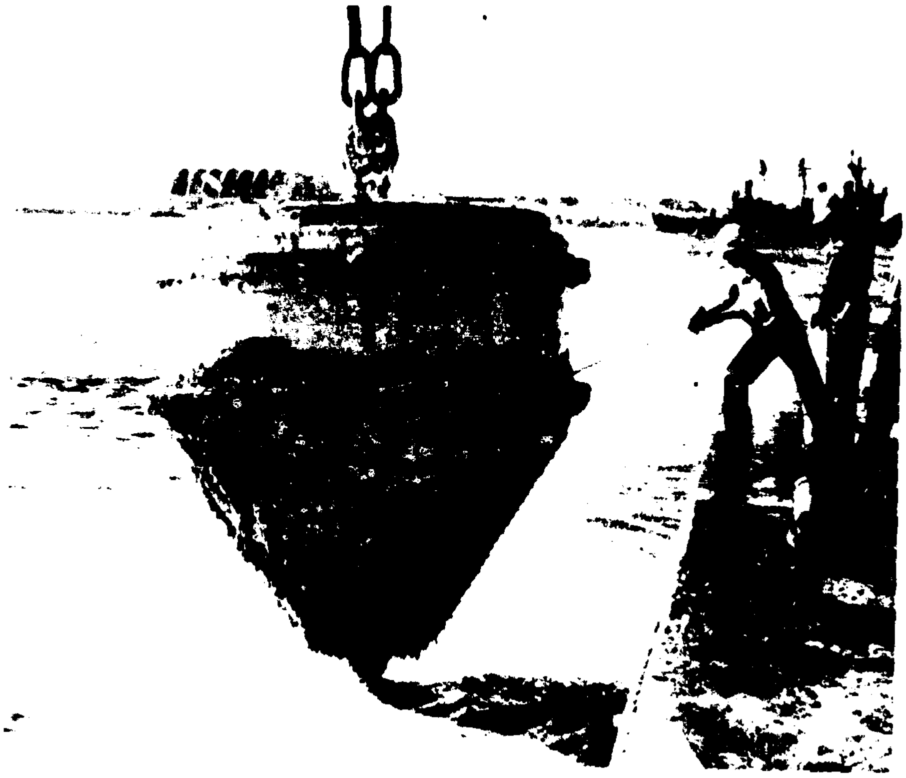

Figure 3. Hosing off System 2 buoy.

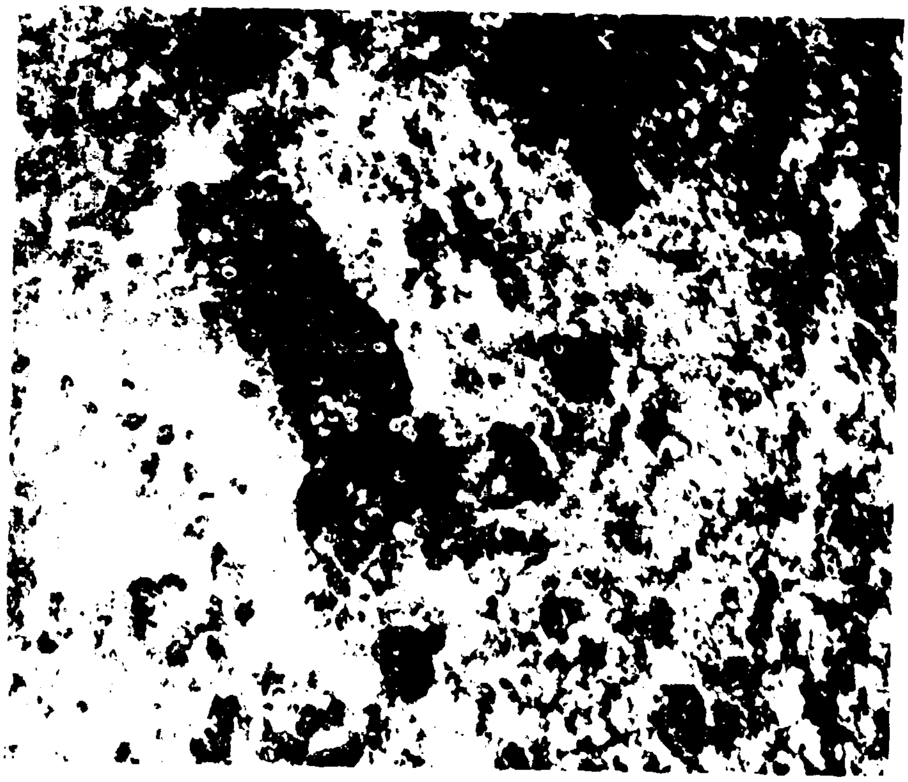

Figure 4. Epoxy patch on System 2 buoy.

Figure 5. System 3 buoy after removal of fouling.

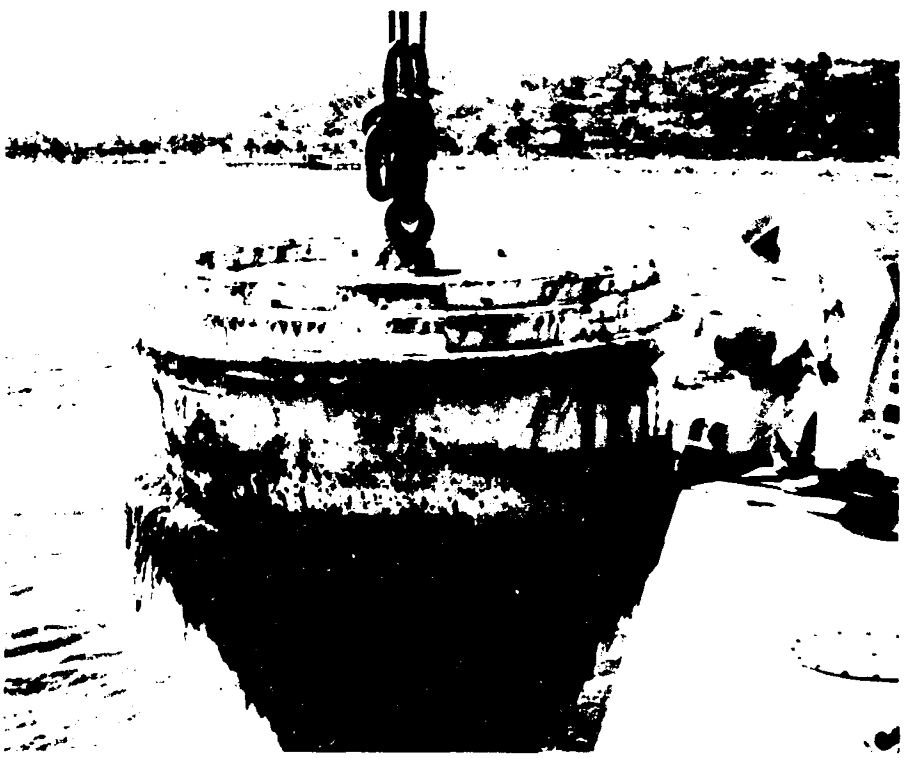

Figure 6. Determining chalking on System 5 buoy before hosing off fouling.

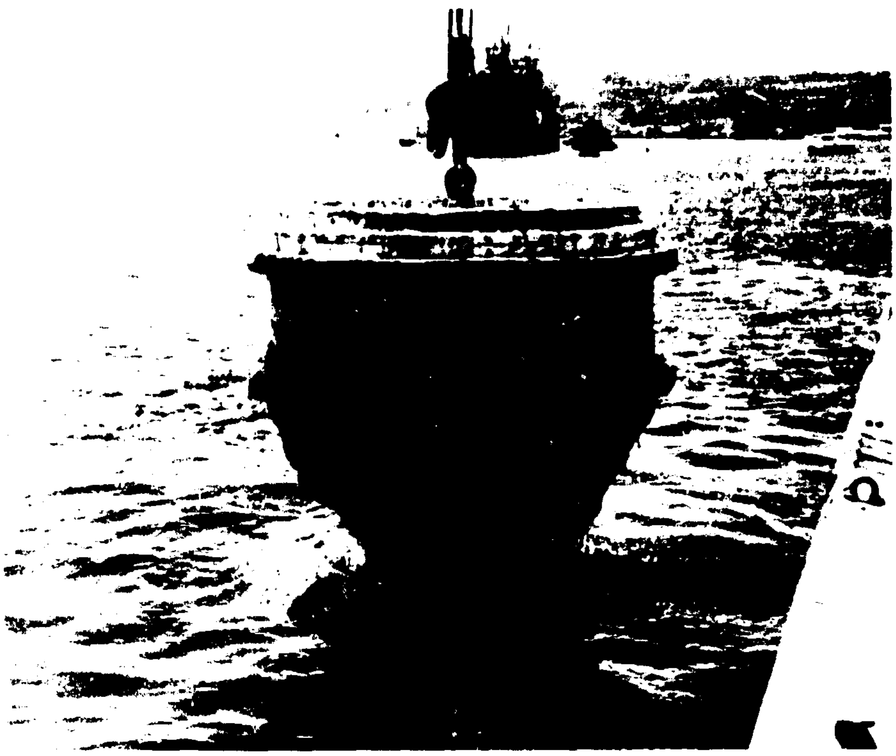

Figure 7. System 6 buoy before removal of fouling.

Coating System 7C: Phenolic

The condition of the System 7C buoy had not changed appreciably since the last inspection. The previously noted[6-8] blistering in the submerged zone had not increased perceptibly. The slight flaking of the antifouling coating in this area was probably aggravated by barnacle attachment, since the antifouling coating had long since lost its effectiveness. The cathodic-protection system on this buoy was still very effective in mitigating rusting where bare steel was exposed underwater.

Coating System 8: Phenolic-Alkyd

The condition of the System 8 buoy (Figure 8) had not changed appreciably since the last inspection. The submerged portion of this buoy had the identical coating system used on the System 7C buoy, and consequently, the condition of the coating system in this area on both of these buoys was quite similar. There was, however, more rusting in this area of the System 8 buoy, since it did not receive cathodic protection. Rusting on the side of the buoy was either of the pinpoint variety or had been caused by abrasion.

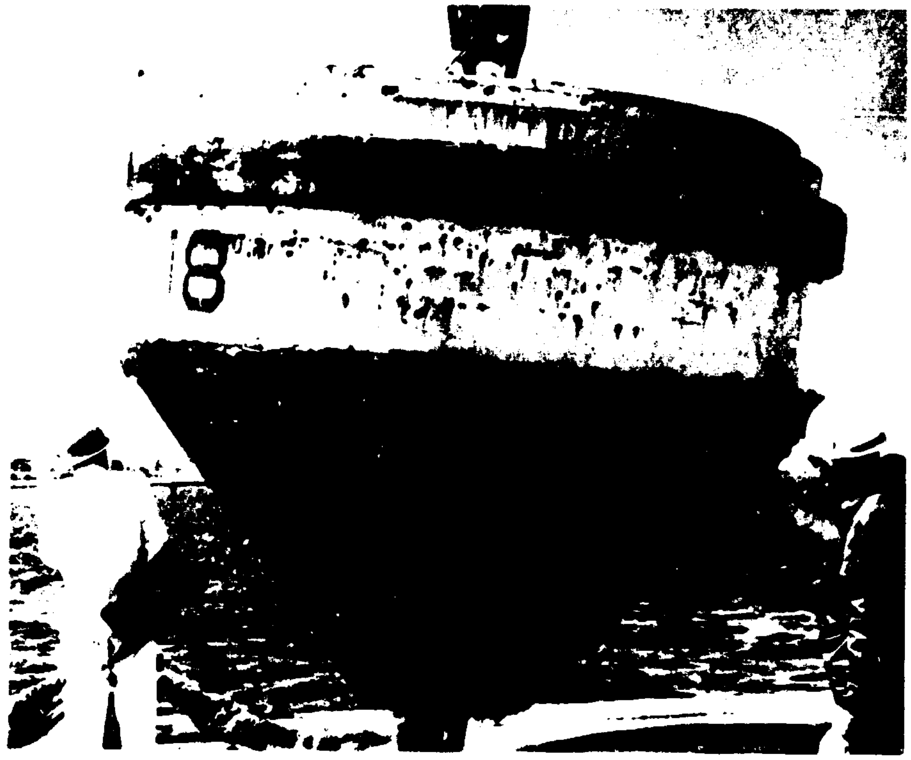

Figure 8. System 8 buoy after removal of fouling.

Coating System 9: Vinyl

The condition of the System 9 buoy (Figure 9) had changed very little since the last inspection. The coating on the side and underwater portions of the buoy had been damaged 1 year previously, probably by abrasion. The underwater-curing epoxy patches applied to these areas at that time, as well as three smaller ones applied 6 months later, were all in good condition and protecting the underlying steel. About eight additional small damaged spots on the underwater portion were now in evidence. It appeared that these were areas that had been damaged 1 year earlier, but were too small to require patching until undercutting of the vinyl system had enlarged them to their present size. These were cleaned and patched with underwater-curing epoxy in the manner previously used.[7,8] The type and amount of fouling on this buoy were similar to those on test buoys without an antifouling coating.

Coating System 10: High-Body Vinyl

Because of advanced corrosion, the System 10 buoy had been removed from testing after 35 months of service.

Coating System 11: Vinyl Mastic

Because of advanced corrosion, the System 11 buoy had been removed from testing after 19 months of service.

Coating System 12: Inorganic Zinc Silicate—Vinyl Mastic

The System 12 buoy had received extensive use since the last inspection and had been dragged 70 feet out of alignment with adjacent buoys. Because of its heavy usage, it was necessary to inspect the buoy with a ship still secured to it (Figure 10).

The condition of the coating had changed very little since the last inspection. Although half of the organic primer and topcoat had been lost from the submerged portion during the first 6 months of testing, the underlying inorganic zinc silicate coating had been quite effective in mitigating corrosion. The gradual loss of zinc had permitted rusting, but thus far the rust had been light and free of pitting.

Coating Systems 13 and 13C: Saran

Systems 13 and 13C were identical, but System 13C was applied to a cathodically protected buoy. Due to maintenance scheduling problems associated with the lighting system of the System 13 buoy, it has remained in the mooring yard since the last inspection.

The condition of the coating on both buoys had not changed much since the last inspection. Most rusting was due to abrasion or was of the pinpoint variety. The System 13C buoy (Figure 11) was free of rusting in the submerged zone because of its cathodic protection. The square of bare steel previously exposed on the cone of this buoy was also free of rust but had some barnacle fouling.

CONDITION OF PANEL COATINGS

The coating system of each panel is rated in Table 3, and the ratings of the specific properties are given in Appendix B. There continues to be a distinct difference in the type of fouling at the two panel-testing sites. While barnacles were conspicuous at both locations, they formed on all San Diego panels without an antifouling paint, a heavy crust that probably afforded significant protection to the panels. Mussels and bryozoa were much more numerous and larger at Port Hueneme. Conversely, tunicates and sponges were most conspicuous at San Diego, but virtually absent at Port Hueneme.

Figure 9. System 9 buoy after removal of fouling.

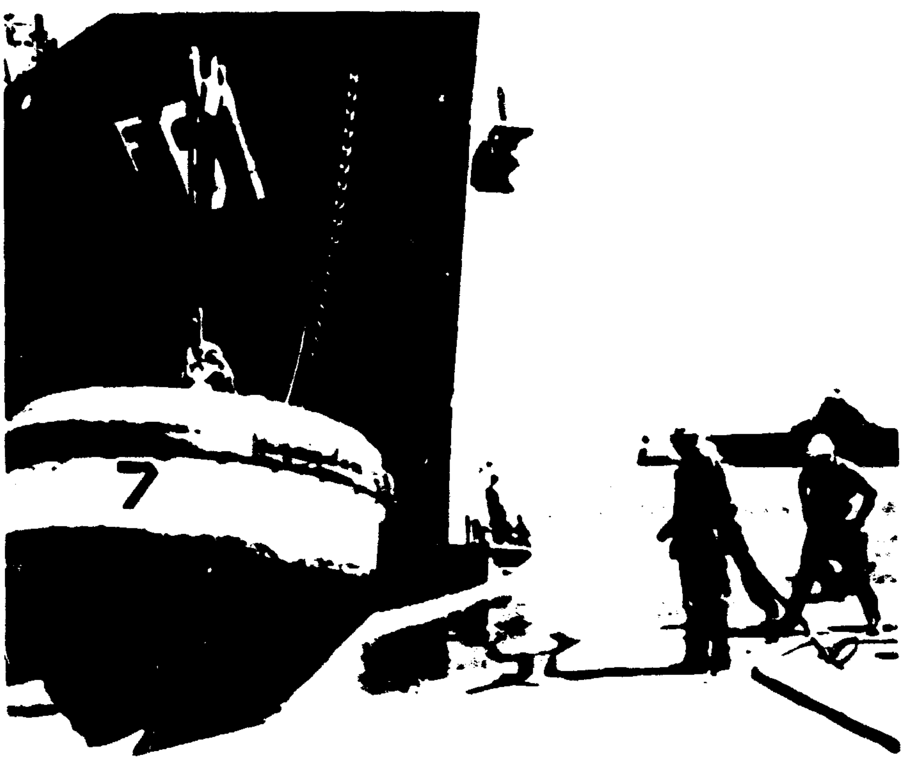

Figure 10. Hosing System 12 buoy with ship secured.

Table 3. Overall Ratings of Coated Panels After 3-1/2 Years

Coating System		Rating[1]	
Number	Description	Port Hueneme	San Diego
1	Urethane	8	9
2	Epoxy	10	10
3	Epoxy–Polyester	9	9
4	Epoxy–Coal Tar Epoxy	10	10
5	Coal Tar Epoxy–Phenolic	9	9
6	Phenolic Mastic	10	10
7C	Phenolic	9	9
8	Phenolic–Alkyd	9	9
9	Vinyl	10	10
10	High-Body Vinyl	–[2]	–[2]
11	Vinyl Mastic	–[2]	–[2]
12	Inorganic Zinc Silicate–Vinyl Mastic	8	8
13	Saran	9	9

1/ 10 = perfect condition; 0 = complete deterioration.
2/ Systems No. 10 and 11 failed and were eliminated from test.

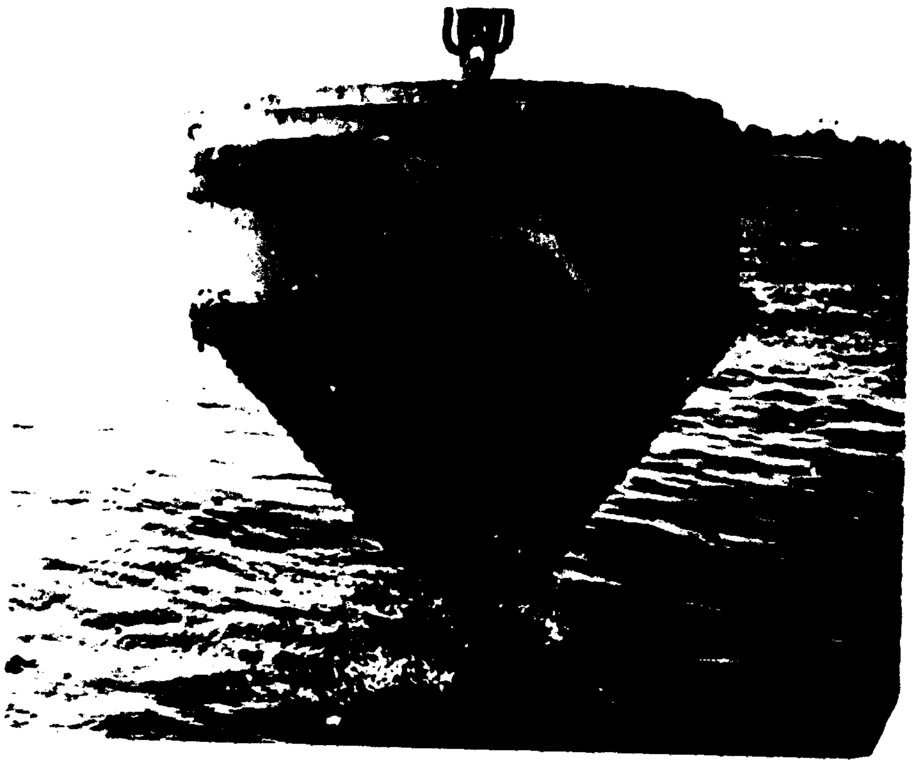

Figure 11. System 13C buoy after removal of fouling.

Coating System 1: Urethane

Both urethane-coated panels were little changed since the last inspection. The slight coating deterioration on the San Diego panel is mostly at the edge. The small blisters and the slight delamination of topcoat on one side of the Port Hueneme panel noted at the time of the last inspection[8] had not increased to a noticeable extent.

Coating System 2: Epoxy

Both epoxy-coated panels were receiving excellent protection. The white antifouling paint originally used on these panels had long since been lost,[4-6] but this had not affected the protection afforded by the epoxy system. In order to determine if this system could be used with other, more conventional antifouling paints, two panels were coated with Coating System 2; one was then coated with vinyl antifouling MIL-P-15931A, and the other with a proprietary copper oxide-containing polyester antifouling.[7,8] After 1-1/2 years of exposure in Port Hueneme Harbor, both panels were in excellent condition and both had only light fouling.

Coating System 3: Epoxy—Polyester

As previously reported,[4-8] when the antifouling coating (identical to that used with System 2) was lost from the System 3 panels, it took the polyester coats with it, thus exposing the underlying epoxy primer. This primer continued to provide good protection at both locations. The slight rusting on both panels was largely restricted to the edges.

Coating System 4: Epoxy—Coal Tar Epoxy

Neither System 4 panel had shown any deterioration other than slight edge rusting on the San Diego panel.

Coating System 5: Coal Tar Epoxy—Phenolic

On both System 5 panels, the white topcoat had previously been almost completely lost,[3-8] in the tidal and submerged zones, exposing the underlying seal coat. The seal coat and coal tar epoxy undercoat continued to provide good protection, with the slight rusting present restricted to panel edges.

Coating System 6: Phenolic Mastic

The System 6 panel showed no deterioration in any zone at Port Hueneme and only slight edge rusting in the submerged zone at San Diego.

Coating System 7C: Phenolic

The System 7C panels were very little changed since the last inspection. There was no increase in the number of small blisters previously noted[8] in the submerged zone. The slight rusting was concentrated along panel edges. Greater amounts of primer continued to be exposed by the gradual erosion of the black antifouling coating, but there continued to be less fouling on the System 7C panels than on adjacent panels without an antifouling coating.

Coating System 8: Phenolic—Alkyd

System 8 is identical to 7C in the tidal and submerged zones; consequently, the conditions of the two coating systems in these areas were similar. The coatings in the atmospheric zones of these systems, though different, were both providing relatively good protection.

Coating System 9: Vinyl

Both System 9 panels were free of corrosion. Although the antifouling coating continued to erode away gradually, thus exposing the underlying primer, there continued to be less fouling on the System 9 panels than on panels without an antifouling coating (see Table 1).

Coating System 10: High-Body Vinyl

Both System 10 panels were previously removed from test because of coating failure.

Coating System 11: Vinyl Mastic

Both System 11 panels were previously removed from test because of coating failure.

Coating System 12: Inorganic Zinc Silicate—Vinyl Mastic

The Port Hueneme panel had lost about 70% of its vinyl mastic coating in the tidal zone and 20% in the submerged zone. The exposed zinc silicate coating had lost much of its effectiveness in mitigating rusting. The San Diego panel had lost almost all of the vinyl mastic coating in the submerged and tidal areas where there was rusting and slight pitting.

Coating System 13: Saran

Both Saran-coated panels were still in relatively good condition. Most of the corrosion present consisted of pinpoint or edge rusting.

CATHODIC-PROTECTION RESULTS

At the time of the previous inspection, the potentials of the three cathodically protected buoys (Systems 6C, 7C, and 13C) were -870, -780, and -820 mv, respectively, as compared to a reference silver/silver chloride half-cell. When measured during this inspection, the potentials of System 7C and 13C buoys were both -870 mv, well above the minimum necessary for complete protection. A Navy ship was secured to the System 6C buoy for much of the inspection period. Immediately after the ship had departed, the buoy potential was -750 mv. The average potential of buoys without cathodic protection was about -670 mv.

Additional proof of the satisfactory performance of the cathodic-protection systems was given by the appearance of the zinc anodes. After removal of the loose, yellowish film from the anodes during the high-pressure hosing of the buoy fouling, the zinc surfaces were clean and crystalline in appearance. The sacrificial anodes had become appreciably reduced in thickness (Figures 12 and 13) since their original installation 28 months earlier, but there appeared to be sufficient zinc left to provide protection for another year.

The cathodically protected buoys had considerably less rusting than the unprotected control buoys. The foot-square section of bare steel previously exposed by power wire brushing[3-8] of the cone of the System 13C buoy was virtually free of rust. The riser chains of the protected buoys were also in better conditions than those of the buoys without cathodic protection. There was considerably less corrosion and loss of coal tar coating on the former riser chains, and the rust there was in a thin, uniform layer. The unprotected riser chains had alternate areas of bright and rusted steel, indicating active corrosion. It has previously been shown[11] that some of the protection from cathodically protected buoys is transferred down tight riser chains.

DISCUSSION

The condition of the buoy-coating systems at the time of each inspection is summarized in Table 4. It can be seen from this table that relatively little change occurred during the last 6 months.

At the time of this inspection, only three of the coating systems (Systems 2, 6C, and 13C) on test buoys were rated as good; seven (Systems 1, 4, 6, 7, 8, 9, and 13) were rated as good-fair; two (Systems 3 and 5) were rated as fair; one (System 12) was rated as fair-poor; and two of the test buoys (Systems 10 and 11) had previously been removed from test because of coating failure. The coating systems generally performed better on the test panels than on the buoys, because the latter were subject to impact and abrasion damage during service to the Fleet. Nine of the original thirteen coating systems on test panels are still rated as 9 or 10. These include all of the systems rated as good on test buoys and all but one rated as good-fair. The ratings of 9 were frequently due to edge damage that occured during handling.

The System 2 (epoxy) buoy is currently the test buoy in the best condition. It is the only buoy without cathodic protection that was rated good. It should be noted that this is a Mark I buoy with lighter fendering than the Mark II buoys, and consequently, it has received less protection from impact and abrasion than the Mark II test buoys. Although the original antifouling coating performed poorly on the System 2 buoy and test panels (as well as on those of System 3), other antifouling coatings have been found to perform well over this coating system.

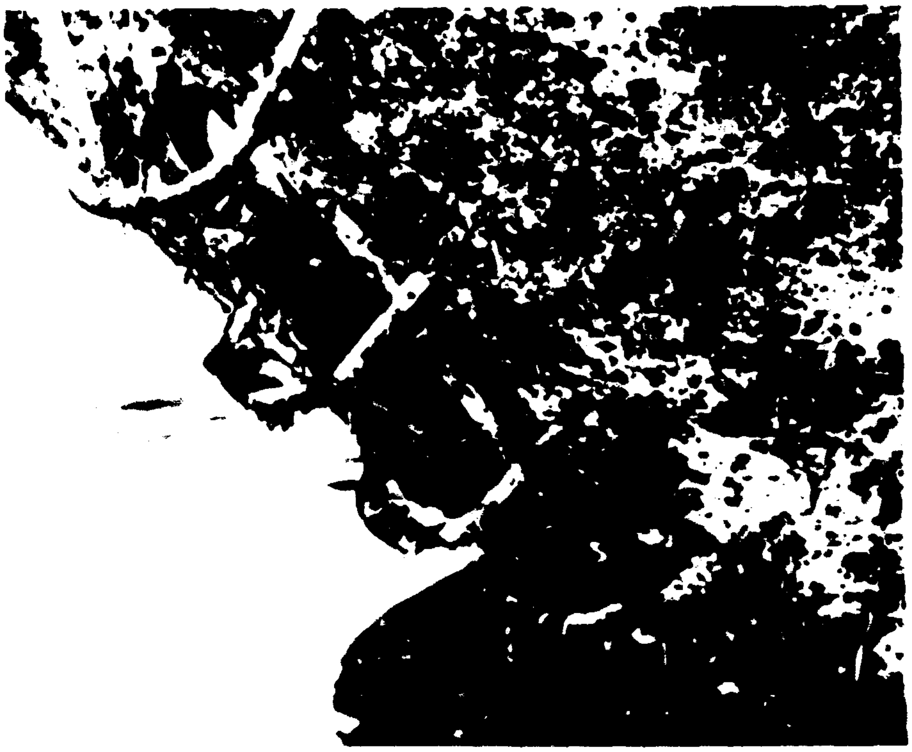

Figure 12. Zinc anode on System 6C buoy.

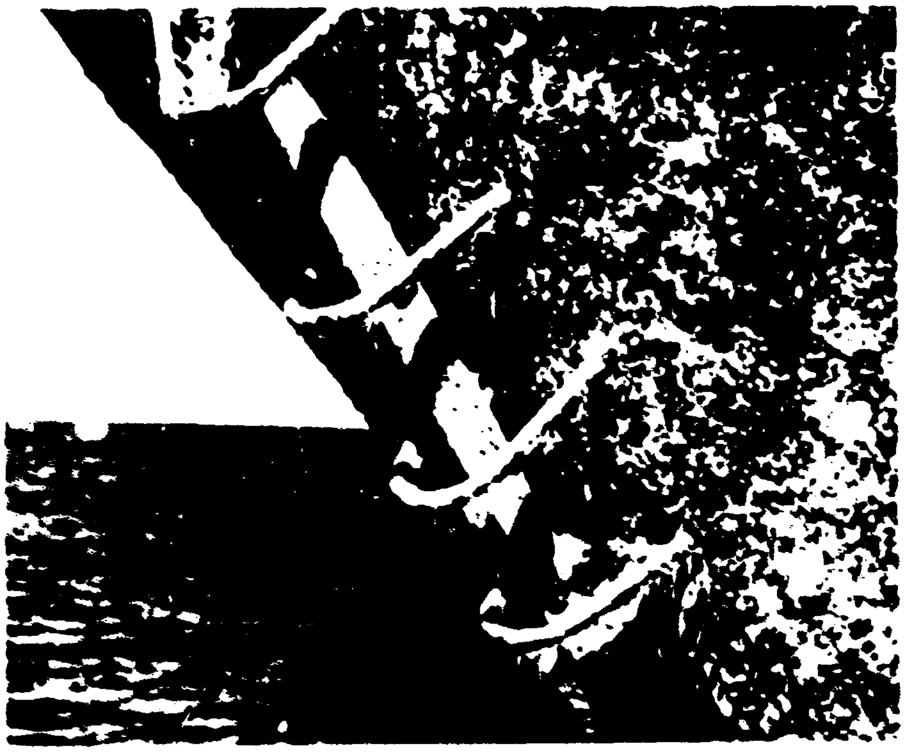

Figure 13. Zinc anode on System 7C buoy.

Table 4. Condition of Buoy Coatings at Time of Each Inspection 1/

Coating System								
1	G	G	G	G	G-F	G-F	G-F	G-F
2	G	G	G	G	G	G	G	G
3	G	F	F	F	F	F	F	F
4	G	G-F	G-F	G-F	G-F	G-F	G-F	G-F
5	G	G-F	F	F	F	F	F	F
6	G	G	G	G	G-F	G-F	G-F	G-F
6C	G	G	G	G	G	G	G	G
7C	G	G	G	G	G-F	G-F	G-F	G-F
8	E	G	G	G	G-F	G-F	G-F	G-F
9	E	E	G	G	G	G	G-F	G-F
10	G	F	F	F	F	P 2/		
11	P	P	P 2/					
12	F	F	F	F	F	F	F-P	F-P
13	G	G-F	G-F	G-F	G-F	G-F	G-F	G-F
13C	G	G	G	G	G	G	G	G

Cumulative Time (months): 6, 12, 18, 24, 30, 36, 42, 48, 54

1/ Ratings:
E = excellent
G = good
F = fair
P = poor

2/ Removed from test after failure.

The coating system on buoys 6 and 6C (phenolic mastic) has performed well, but there was appreciable abrasion damage to these buoys during their first 2 years of service. Further abrasion damage had not occurred to any extent during the last year, and the System 6 panels were in excellent condition. This system has performed well in the steel sheet piling study of Alumbaugh and Brouillette.[12]

System 13C (Saran), which was rated as good, also performed well for Alumbaugh and Brouillette.[12] The main difficulty with Saran is its tendency to permit pinpoint rusting.

Coating System 1 (urethane) was in fairly good condition on both the buoys and the panels, but there was some rusting associated with blistering on both.

Coatings Systems 7C (phenolic) and 8 (phenolic–alkyd) were both in relatively good condition on both the test panels and the buoys. With both systems, deterioration in the atmospheric zone of the test buoy was mostly due to abrasion, and deterioration below water was due to gradual loss of the antifouling coating. Because of the type of fouling in San Diego Bay and the periodic inspection of the test buoys (at which time fouling is removed by high-pressure hosing), use of an antifouling paint is unnecessary. In addition, the antifouling properties of these paints is greatly diminished after 2 years. The longer life of the antifouling coating on the test panels is probably due to a lower rate of leaching by the weaker currents of the water in which they were exposed.

Coating System 9 (vinyl) is another example where the coating on the test buoy is in relatively good condition, and deterioration below water is associated with gradual loss of the antifouling coat. If the system used above water had also been used below, the buoy might be in much better condition, because the gradual erosion of the antifouling continues to expose the underlying primer.

Coating System 3 (epoxy–polyester) was providing good protection to both the buoy and panels despite the loss of much of the polyester topcoating below water.

Coating System 4 (epoxy–coal tar epoxy) was providing good protection to both the buoy and the panels. Much of the epoxy topcoat and seal coat had been lost from the buoy below water, but this had not occurred on either test panel. Conversely, Coating System 5 (coal tar epoxy–phenolic) had lost much of the phenolic topcoat from the submerged portion of the panels, but this was not occurring on the buoy. The seal coat and underlying coal tar epoxy remaining on the System 5 test panels was continuing to provide good protection to the steel.

The System 12 (inorganic zinc silicate–vinyl mastic) buoy had not had a great increase in rusting since the previous inspection. It appeared that some protection was still being imparted by zinc still present in the primer.

The good performance of underwater-curing epoxies in patching coatings damaged by abrasion indicates that such a use of these materials may result in a considerable savings of maintenance funds.

The zinc anodes on three of the test buoys had been quite effective in retarding corrosion on the underwater portions of these buoys and their riser chains. Should the zinc anodes perform satisfactorily for an additional 8 months (which seems most likely), their yearly material cost will have been $13.

FINDINGS

1. On three of the test buoys, the coating systems were in good condition; seven others were rated as good-fair, two as fair, and one as fair-poor. Two buoys had previously been removed from test because of coating failure.

2. Two antifouling paints on test panels were still effective in reducing the amount of fouling to an appreciable extent after 3-1/2 years; on test buoys, they had lost their effectiveness after 20 months.

3. Patches of underwater-curing epoxy applied to damaged areas of several different coating systems were quite effective in protecting steel from corrosion below water. Some of these patches have performed well for 3-1/2 years.

4. Zinc anodes were effectively mitigating underwater corrosion on the three cathodically protected buoys. Although the anodes were appreciably reduced in size, they should continue to perform effectively for another year.

CONCLUSIONS

1. The protective coating systems still under test are giving greater service life to the test mooring buoys than the service life generally received at field activities. Some of the better coating performance is due to better surface preparation and coating application.

2. The use of an antifouling coating on the underwater portion of mooring buoys is not justified unless fouling is known to consititute a maintenance or operational problem.

3. Underwater-curing epoxies can greatly extend the service life of mooring buoys where localized areas of coating have been damaged by abrasion.

4. Zinc anodes can effectively mitigate underwater corrosion on mooring buoys at a very low cost.

RECOMMENDATIONS

1. The coating systems that have performed well to date in the present test should be considered for use by field activities of the Naval Shore Establishment.

2. Underwater-curing epoxies should be carried by field crews inspecting or relocating moorings so that localized areas of damaged coatings can be repaired in place.

3. A greater use should be made of zinc anodes in cathodically protecting fleet moorings.

4. Treated wood should be used on the lower fenders of Mark I buoys to protect them from marine borer attack.

ACKNOWLEDGMENT

Mr. A. F. Curry of NCEL made an independent rating of the coated buoys and both sets of test panels.

Appendix A

RATINGS OF BUOYS WITH TEST COATINGS

Coating System 1: Urethane

No. of Months in Service: 51 — Overall Condition: Good-Fair

Amount of Use: Heavy — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	2	2	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I 1/	9	8	9
Rusting, Type II 2/	10	10	10
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	broken fender	dent in steel plate

1/ Without blistering.
2/ With blistering.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 2: Epoxy

No. of Months in Service: 49

Overall Condition: Good

Amount of Use: Light

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	—
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	N	dent in steel plate

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 3: Epoxy–Polyester

No. of Monthes in Service: 49 — Overall Condition: Fair

Amount of Use: Light — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	6 1/	6 1/
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	–	M	M
Guano, amount	L	–	–
Structural damage	fender splintered	N	fender splintered

1/ Topcoat lost, primer exposed.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 4: Epoxy–Coal Tar Epoxy

No. of Months in Service: 51

Overall Condition: Good-Fair

Amount of Use: Heavy

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	2	2	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	6 1/
Erosion	10	10	10
Rusting, Type I	9	9	10
Rusting, Type II	10	10	10
Fouling, amount	–	M	H
Guano, amount	L	–	–
Structural damage	N	N	N

1/ Delamination of topcoat and seal coat, exposing coal tar epoxy coating.

Note. For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H heavy, L light, M medium and N none.

Coating System 5: Coal Tar Epoxy–Phenolic

No. of Months in Service: 49 — Overall Condition: Fair

Amount of Use: Heavy — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	7 1/	9	9 2/
Rusting, Type II	10	10	10
Fouling, amount	–	H	H
Guano, amount	L	–	–
Structural damage	N	N	dent in steel plate

1/ Mostly from abrasion of coating by securing assembly.
2/ Rivet heads were badly corroded.

Note For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H heavy, L light, M medium and N none.

Coating System 6: Phenolic Mastic

No. of Months in Service: 49 — Overall Condition: Good-Fair

Amount of Use: Light — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	8 1/	9 1/	9 1/
Rusting, Type II	10	10	10
Fouling, amount	–	H	H
Guano, amount	L	–	–
Structural damage	dent in side; broken fender	broken fender	dent in steel plate

1/ Mostly from abrasion of coating.

Note For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H heavy, L light, M medium and N none.

Coating System 6C: Phenolic Mastic

No. of Months in Service: 49 — Overall Condition: Good

Amount of Use: Heavy — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	--
Chalking	10	10	-
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	7 1/	9 1/	9 1/
Rusting, Type II	10	10	10
Fouling, amount	—	H	H
Guano, amount	L	—	—
Structural damage	fender splintered	N	N

1/ Mostly from abrasion of coating.

Note For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 7C: Phenolic

No. of Months in Service: 44 | Overall Condition: Good-Fair

Amount of Use: Medium | Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	6	6	–
Blistering	N, 10	N, 10	F, 8
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	8 1/
Erosion	10	10	8 1/
Rusting, Type I	9 2/	9 2/	10
Rusting, Type II	10	10	10
Fouling, amount	–	M	M
Guano, amount	M	–	–
Structural damage	N	N	slight dent in steel plate

1/ Mostly antifouling paint.
2/ Mostly from abrasion of coating.

Note For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H heavy, L light, M medium and N none.

Coating System 8: Phenolic–Alkyd

No. of Months in Service: 44

Overall Condition: Good-Fair

Amount of Use: Medium

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	10	10	–
Blistering	N, 10	N, 10	F, 8
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	8 1/
Erosion	10	10	8 1/
Rusting, Type I	9 2/	9 2/	9
Rusting, Type II	10	10	9
Fouling, amount	–	M	M
Guano, amount	M	–	–
Structural damage	N	N	N

1/ Mostly antifouling paint.
2/ Mostly from abrasion at coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 9: Vinyl

No. of Months in Service: 45

Overall Condition: Good-Fair

Amount of Use: Light

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	10	–
Chalking	10	10	–
Blistering	N, 10	N, 10	N, 10
Checking	N, 10	10	10
Cracking	N, 10	10	10
Flaking (scaling)	N, 10	9 1/	10
Erosion	N, 10	10	9
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	–	M	M
Guano, amount	M	–	–
Structural damage	N	dent in steel plate	dent in steel plate

1/ Mostly antifouling paint

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 12: Inorganic Zinc Silicate—Vinyl Mastic

No. of Months in Service: 51

Overall Condition: Fair-Poor

Amount of Use: Heavy

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	5 1/
Erosion	10	10	10
Rusting, Type I	9 2/	9 2/	8
Rusting, Type II	10	10	10
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	N	dent in steel plate

1/ Topcoat only.
2/ Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 13: Saran

No. of Months in Service: 49

Overall Condition: Good-Fair

Amount of Use: Light

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	8[1]	9[2]	9[2]
Rusting, Type II	10	10	9
Fouling, amount	—	3/	3/
Guano, amount	3/	—	—
Structural damage	N	fender splintered; dent in steel plate	N

1/ Mostly from abrasion of coating.
2/ Mostly pinpoint rusting.
3/ No fouling or guano present because buoy had been taken ashore for structural repai.s.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 13C: Saran

No. of Months in Service: 50 — Overall Condition: Good

Amount of Use: Medium — Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9 1/	10
Rusting, Type II	10	10	10
Fouling, amount	–	M	M
Guano, amount	H	–	–
Structural damage	dent in steel plate	dent in steel plate	N

1/ Mostly pinpoint rusting.

Note. For chalking, blistering, checking, cracking, flcking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H heavy, L light, M medium and N none.

Coating System No.	1 (Urethane)						2 (Epoxy)						
Exposure Site	PH			SD			PH			SD			
Panel Zone	A[1]	T[2]	S[3]	A	T	S	A	T	S	A	T	S	A
General Protection	8	7	9	9	9	9	10	10	10	10	10	10	9
Chalking	4	—	—	—[12]	—	—	8	—	—	—	—	—	8
Checking	9	10	10	10	10	10	10	10	10	10	10	10	10
Blistering, size	2	8	10	10	10	10	10	10	10	10	10	10	10
Blistering, frequency	F[15]	F	N[9]	N	N	N	N	N	N	N	N	N	N
Flaking	10	7[7]	10	10	10	10	10	10	10	10	10	10	10
Cracking	10	10	10	10	10	10	10	10	10	10	10	10	10
Undercutting	10	10	10	10	10	10	10	10	10	10	10	10	10
Rusting, type I	9	9[10]	9[10]	9[10]	9[10]	9[10]	10	10	10	10	10	10	9[10]
Rusting, type II	8	7	10	10	10	10	10	10	10	10	10	10	10
Pitting	10	10	10	10	10	10	10	10	10	10	10	10	10
Fouling, amount	—	H[11]	H	—	H	M[6]	—	H	H	—	H	M	—
Fouling, area[4]	—	1	1	—	0	4	—	1	2	—	1	2	—
1. Plant Area	—	2	4	—	8	8	—	9	8	—	9	9	—
2. Animal Area	—	8	6	—	1	5	—	1	3	—	1	3	—
a. Tunicates	—	10	10	—	10	8	—	10	10	—	10	8	—
b. Barnacles	—	8	9	—	3	9	—	2	9	—	3	9	—
c. Mussels	—	10	7	—	8	8	—	4	8	—	8	8	—
d. Bryozoa	—	10	8	—	10	8	—	10	8	—	10	9	—
e. Hydroids	—	10	8	—	10	8	—	10	7	—	10	8	—
f. Tube Worms	—	10	10	—	9	9	—	10	9	—	10	9	—
g. Sponges	—	10	10	—	10	8	—	10	10	—	10	9	—
Overall Rating		8			9			10			10		

1/ A = atmospheric zone
2/ T = tidal zone
3/ S = submerged zone
4/ 0 = 100% fouled; 10 = 0% fouled
5/ Antifouling coat only
6/ M = medium
7/ Delamination of topcoat on one side of panel
8/ L = light
9/ N = none
10/ Mostly at edge
11/ H = heavy

A

Appendix B — RATING OF TEST PANELS AT PORT HUENEME AND SAN DIEGO

2 (Epoxy)				3 (Epoxy–Polyester)						4 (Epoxy–Coal Tar Epoxy)						5 (Coal Tar Epoxy–			
	SD			PH			SD			PH			SD			PH			
S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A
10	10	10	10	9	10	10	9	9	9	10	10	10	9	10	9	9	10	10	9
—	—	—	—	8	—	—	—	—	—	10	—	—	—	—	—	4	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
10	10	10	10	10	1[14]	1[14]	10	1[14]	1[14]	10	10	10	10	10	10	10	0[16]	3[16]	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	9[10]	10	10	9[10]	9[10]	9[10]	10	10	10	9[10]	10	9[10]	9[10]	10	9[10]	9[10]
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
H	—	H	M	—	H	H	—	H	M	—	H	M	—	H	M	—	H	H	—
2	—	1	2	—	1	1	—	0	1	—	2	1	—	0	3	—	1	1	—
8	—	9	9	—	9	9	—	8	8	—	9	8	—	9	9	—	8	8	—
3	—	1	3	—	2	2	—	1	1	—	1	4	—	1	5	—	2	2	—
10	—	10	8	—	10	10	—	10	8	—	10	10	—	10	8	—	10	10	—
9	—	3	9	—	2	9	—	2	10	—	2	9	—	3	9	—	3	8	—
8	—	8	8	—	10	6	—	8	8	—	6	6	—	8	8	—	4	9	—
8	—	10	9	—	10	7	—	10	9	—	10	7	—	10	8	—	10	4	—
7	—	10	8	—	10	6	—	10	8	—	10	7	—	10	8	—	10	4	—
9	—	10	9	—	10	10	—	10	9	—	10	10	—	9	9	—	10	9	—
10	—	10	9	—	10	10	—	9	9	—	10	10	—	10	8	—	10	10	—
		10			9			9			10			10			9		

edium
ation of topcoat on
of panel
ht
ne
t edge
avy

12/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection
13/ A few pin holes only
14/ Antifouling and topcoat lost exposing primer
15/ F = few
16/ Loss of topcoat exposing gray seal coat

17/

18/

ME AND SAN DIEGO

xy–Coal Tar Epoxy)				5 (Coal Tar Epoxy–Phenolic)						6 (Phenolic Mastic)					
	SD			PH			SD			PH			SD		
S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
10	9	10	9	9	10	10	9	9	9	10	10	10	10	10	9
—	—	—	--	4	—	—	—	—	—	—	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
10	10	10	10	10	0 [16]	3 [16]	10	0 [16]	0 [16]	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	9 [10]	10	9 [10]	9 [10]	10	9 [10]	9 [10]	9 [10]	9 [10]	10	10	10	10	10	9 [10]
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
M	—	H	M	—	H	H	—	H	H	—	H	M	—	H	H
1	—	0	3	—	1	1	—	0	0	—	1	0	—	2	1
8	—	9	9	—	8	8	—	9	5	—	9	9	—	9	9
4	—	1	5	—	2	2	—	1	4	—	1	0	—	1	2
10	—	10	8	—	10	10	—	10	8	—	10	10	—	10	8
9	—	3	9	—	3	8	—	2	9	—	2	9	—	2	10
6	—	8	8	—	4	9	—	8	8	—	8	5	—	8	8
7	—	10	8	—	10	4	—	10	9	—	10	7	—	10	9
7	—	10	8	—	10	4	—	10	8	—	10	7	—	10	9
10	—	9	9	—	10	9	—	9	9	—	10	10	—	10	10
10	—	10	8	—	10	10	—	9	9	—	9	9	—	9	9
	10			9			9			10			10		

alking on San Diego
y high tide at time

st exposing primer

ay seal coat

17/ Systems No. 10 and 11 failed and eliminated from test

18/ Delamination of primer and topcoat exposing zinc silicate coating

C

Coating System No.	7C (Phenolic)						8 (Phenolic–Alkyd)				
Exposure Site	PH			SD			PH			SD	
Panel Zone	A	T	S	A	T	S	A	T	S	A	T
General Protection	10	9	9	9	9	9	10	10	10	9	9
Chalking	6	—	—	—	—	—	4	—	—	—	—
Checking	10	10	10	10	10	10	10	10	10	10	10
Blistering, size	10	8	8	10	8	8	10	8	8	10	8
Blistering, frequency	N	M	M 18/	N	M	M	N	M	M	N	M
Flaking	10	10	10	10	10	10	10	10	10	10	10
Cracking	10	10	10	10	10	10	10	10	10	10	10
Undercutting	10	0	10	10	10	10	10	10	10	10	10
Rusting, type I	9 10/	9 10/	9 10/	9	9 10/	9 10/	10	10	10	9 10/	9 10/
Rusting, type II	10	10	10	10	10	10	10	10	10	10	10
Pitting	10	10	10	10	10	10	10	10	10	10	10
Fouling, amount	—	L 8/	L	—	M	L	—	L	L	—	M
Fouling, area	—	3	5	—	5	6	—	9	7	—	3
1. Plant Area	—	4	5	—	9	9	—	10	9	—	9
2. Animal Area	—	9	9	—	4	6	—	9	8	—	4
a. Tunicates	—	10	10	—	10	8	—	10	10	—	10
b. Barnacles	—	9	9	—	6	10	—	9	9	—	5
c. Mussels	—	10	10	—	10	9	—	10	10	—	10
d. Bryozoa	—	10	10	—	10	10	—	10	9	—	10
e. Hydroids	—	10	10	—	10	9	—	10	9	—	10
f. Tube Worms	—	10	10	—	10	9	—	10	9	—	10
g. Sponges	—	10	10	—	9	9	—	10	10	—	9
Overall Rating	9			9			9			9	

1/ A = atmospheric zone
2/ T = tidal zone
3/ S = submerged zone
4/ 0 = 100% fouled; 10 = 0% fouled
5/ Antifouling coat only
6/ M = medium
7/ Delamination of topcoat on one side of panel
8/ L = light
9/ N = none
10/ Mostly at edge
11/ H = heavy

8 (Phenolic–Alkyd)					9 (Vinyl)						12[17/] (Inorganic Zinc Silicate–Vinyl Mastic)						
PH		SD			PH			SD			PH			SD			
T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A
10	10	9	9	9	10	10	10	10	10	10	10	7	9	10	7	7	1
—	—	—	—	—	10	—	—	—	—	—	10	—	—	—	—	—	1
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	1
8	8	10	8	8	10	9[5/]	10	10	10	10	10	10	10	10	10	10	1
M	M	N	M	M	N	N	N	N	N	N	N	N	N	N	N	N	N
10	10	10	10	10	10	10	10	10	10	10	10	3[18/]	8[18/]	10	0[18/]	2[18/]	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	9[10/]	9[10/]	9[10/]	10	10	10	10	10	10	10	7	9	10	8	9	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	9
L	L	—	M	L	—	L	L	—	M	L	—	M	M	—	H	H	—
9	7	—	3	5	—	2	3	—	4	6	—	4	1	—	0	1	—
10	9	—	9	8	—	2	3	—	9	8	—	9	9	—	8	8	—
9	8	—	4	6	—	10	9	—	4	7	—	5	8	—	1	2	—
10	10	—	10	7	—	10	10	—	10	8	—	10	10	—	10	6	—
9	9	—	5	10	—	9	10	—	6	9	—	5	9	—	4	9	—
10	10	—	10	9	—	10	10	—	9	9	—	9	8	—	9	9	—
10	9	—	10	10	—	10	9	—	10	10	—	10	7	—	10	6	—
10	9	—	10	9	—	10	10	—	10	9	—	10	8	—	10	7	—
0	9	—	10	9	—	10	10	—	10	9	—	10	10	—	10	9	—
0	10	—	9	9	—	10	10	—	10	9	—	10	10	—	10	9	—
[illegible]		9			10			10			8			8			

of topcoat on
nel

›

12/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection

13/ A few pin holes only

14/ Antifouling and topcoat lost exposing primer

15/ F few

16/ Loss of topcoat exposing gray seal coat

17/ Systems No
from test

18/ Delaminati
zinc silica

		12[17] (Inorganic Zinc Silicate–Vinyl Mastic)						13 (Saran)					
SD		PH			SD			PH			SD		
T	S	A	T	S	A	T	S	A	T	S	A	T	S
10	10	10	7	9	10	7	7	10	9	10	9	9	9
—	—	10	—	—	—	—	—	10	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10
N	N	N	N	N	N	N	N	N	N	N	N	N	N
10	10	10	3[18]	8[18]	10	0[18]	2[18]	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	7	9	10	8	9	10	9[13]	10	9	9	9
10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	9	9	10	10	10	10	10
M	L	—	M	M	—	H	H	—	H	H	—	H	M
4	6	—	4	1	—	0	1	—	2	3	—	1	2
9	8	—	9	9	—	8	8	—	6	8	—	9	9
4	7	—	5	8	—	1	2	—	4	4	—	1	2
10	8	—	10	10	—	10	6	—	10	10	—	10	8
6	9	—	5	9	—	4	9	—	5	9	—	2	9
9	9	—	9	8	—	9	9	—	8	5	—	8	8
10	10	—	10	7	—	10	6	—	10	9	—	10	8
10	9	—	10	8	—	10	7	—	10	7	—	10	9
10	9	—	10	10	—	10	9	—	10	10	—	9	9
10	9	—	10	10	—	10	9	—	10	10	—	9	9
10		8			8			9			9		

chalking on San Diego
mely high tide at time

lost exposing primer

l y-ɔ/ seal coat

17/ Systems No. 10 and 11 failed and eliminated from test

18/ Delamination of primer and topcoat exposing zinc silicate coating

C

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